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NOTES ON THE PHYSICAL GEOGRAPHY OF TEXAS.

BY RALPH S. TARR.

PREFACE.

This paper is based in part upon personal observation, in part upon the published results of others.¹ Free use has been made of the results of the several geologists who have studied the Texas region, and in most cases direct reference has been made to the sources of information. I am particularly indebted to the publications of Prof. R. T. Hill for many geological facts and interpretations, chiefly in the Cretaceous regions where this author has done so much valuable work. With few exceptions, however, the work done by others has been geological rather than physiographic, and consequently I have been in many cases forced to rely upon my own observations alone. Since these were made in sections only, it has not been possible in all cases to make the results as definite as could be desired. My observations were made in 1889 and 1890, the time occupied in field work being almost eight months, the larger part of which was spent in the Central Denuded Area. Aside from this and short excursions and railroad journeys, I also made a wagon journey across the State of Texas from north of Austin to the Guadalupe Mountains in the Trans-Pecos region, and spent several weeks in and about these mountains.

The results embodied herein must therefore be understood to be the results of reconnoissance,—preliminary exploration of a great and interesting field. Were it possible that in the future I should again have the opportunity of studying the region I would delay the publication of this still longer; but this seems to be entirely out of the question, and I believe that I am justified in placing the results of my study on record to serve as a possible basis for future work.

PART I.—GENERAL DESCRIPTION.

1.—GENERAL GEOGRAPHY.²

(a) *Topography*.—The State of Texas consists, in the portion which lies east of the Pecos river, of a series of plains, and west of

¹ The appended bibliography is a partial list of works consulted.

² I shall follow in general the classification offered by Prof. R. T. Hill, (*Am. Geol.*, V, 1890, pp. 9–29,) since this is the only classification offered, and is both natural and accurate.

that river of a great plateau broken by mountain ranges, southern spurs of the Rocky mountains. The plain east of the Pecos is broken in only one place, where the Palæozoic rocks are exposed by the removal of the Cretaceous covering, and this has been called by Professor Hill, the Central Denuded Area.

On the Gulf coast are the Quaternary beds, forming the Coastal Prairies, a great, level tract of land chiefly swampy and but slightly elevated above the Gulf. A forested region of Tertiary sands and clays, carved into gently undulating topography is interposed between the Coastal Prairies and the great Cretaceous plain. The Cretaceous plain, commencing at an elevation, in the vicinity of Austin, of not far from four hundred feet, though varying in different parts, forms one of the greatest geographical units of Texas. It is a treeless prairie, with a few exceptions, and occupies nearly one fourth of the state, rising gradually away from the coast and reaching an elevation of two thousand feet and more.

Partly enclosed in this Prairie is the Central Denuded Area, a region of hilly, sparsely forested Carboniferous and older rocks, which to the west merge into the Red Beds of Permian age. These beds on the east have something of the topographic diversity of the older rocks, but to the west change gradually in topographic form and merge, geographically, almost imperceptibly into the lake or inland sea beds of the Staked Plains, the Llano Estacado. These plains, treeless and arid, form a true plateau with an elevation of from 3,000 to 4,500 feet. The Pecos river flows along the base of the Llano Estacado plateau which ends abruptly in a steep west facing escarpment. To the west there is another plateau, broken by mountain ranges, the Trans-Pecos Mountain and Basin region of Hill.

There are, therefore, six great topographic divisions in Texas:— 1st, the Coastal Prairies; 2nd, the Rolling Forested Tertiary Area; 3rd, the Grand Prairie; 4th, the Central Denuded Area; 5th, the Llano Estacado; 6th, the Trans-Pecos Mountain and Basin Region. To this might be added many minor divisions dependent upon minor topographical or geographical features. East of the Pecos the country is one of plateaus, plains, and prairies, forested only in one of its parts (with one or two exceptions to be hereafter noted). The Central Denuded Area alone is hilly and in no place are there mountains. Buttes, chiefly of Cretaceous strata, form the only striking elevations and these are dignified by the name of mountains by the

settlers, in the absence of more striking elevations. West of the Pecos the country is truly mountainous.

(b) *Drainage*.—The drainage naturally falls into two classes, the western, including the Rio Grande and Rio Pecos which receive their water supply from the mountains of New Mexico, and whose Texas tributaries are withered channels favored with water only at rare intervals; and secondly, those of the east, including the Colorado and Brazos, whose headwaters are withered channels in the Llano Estacado and the Permian plain, and whose lower tributaries, flowing in a humid or sub-humid climate, are the source of constant supply.

2.—GENERAL CLIMATIC CONDITIONS.

Texas is humid in the east, excessively so near the Gulf Coast. The climate in this region, for instance near Galveston, is semi-tropical. Proceeding inland, with increasing elevation comes more temperate conditions. Snow falls, and frost occurs in the greater part of the State, this being due to the cold north winds, "the northers" which are not uncommon during the winter. Even as near the coast as Austin the decrease in rainfall is noticeable, and it is necessary to travel inland from here but a hundred miles or so to reach a subhumid belt. The town of Abilene lies in this subhumid region, and to the west of this the climate becomes rapidly more arid until truly arid conditions are met with, and with this change there is a change in the character of vegetation. The Trans-Pecos region is arid, so is the Llano Estacado and the western Permian. More than a third of the State is arid or subhumid.

3.—GENERAL GEOLOGIC AND GEOGRAPHIC DEVELOPMENT.

(a) *Pre-Carboniferous Land*.—This statement is necessarily generalized and, with the present imperfect state of our knowledge of the geology of large parts of Texas, it may in some details be incomplete. I shall attempt nothing more than seems warranted by the facts at present at hand; but these are sufficient for our present purpose which is to trace the general development of the Texas region.

The oldest part of Texas is the Central Denuded Area, and this has had a very complicated history. There is a Pre-Cambrian area, referred by Mr. Walcott to lower Cambrian³ and later to Algonkian⁴

³ Am. J. Sci., XXVIII, 1884, pp. 431-33.

⁴ Bull. U. S. Geol. Survey, No. 30, 1886, pp. 57-64.

age and which Dr. Comstock⁵ considers true Archean. The extent of this area is at present limited and there is no means of determining its former boundaries. The strata are highly metamorphosed, in part by intrusions of Plutonic rocks. About this core are Cambrian and Silurian strata, according to Dr. Comstock folded and faulted in an extremely complicated manner. These older rocks obtained most of their complication and metamorphism before the beginning of the Carboniferous period, for the strata of the latter age rest with marked unconformity on the northern slopes of the Silurian hills.

What was the limit of this Pre-Carboniferous land we have no exact means of determining, but that the present exposure by no means expresses the original extent of outcrop seems certain from the vast quantities of material in the Carboniferous and later strata. Moreover the conglomeratic and sandy nature of the lower Carboniferous deposits, along their eastern margin, indicates very strongly that beneath the Cretaceous not far distant from this, the older land exists. I believe it more than possible that this buried land extended to the areas of Indian Territory and Arkansas, thus connecting them with the central core of Texas.

Be this as it may, there was, in one part at least, a land area in immediate Pre-Carboniferous time. This land was mountainous in type, so far as structure is concerned, and had practically its present degree of metamorphism.⁶ Whether the land was topographically mountainous or not I cannot say. It certainly was not so in the immediate neighborhood of the Carboniferous, for the valleys and hills which were buried beneath the Carboniferous strata were low and well rounded, being mature in type, much more mature than the present topography of the same district, and quite closely like that of the less hilly parts of New England. For this reason I assume that all the land in the neighborhood had undergone long continued denudation and was mature in geographic form. It was a mountainous area worn to its roots in Pre-Carboniferous time.

(b) *Carboniferous Modification of the older Palæozoic Land.*—The next event in the history is the oncoming of the Carboniferous depression and period of sedimentation, a period introduced apparently in Sub-Carboniferous times and continuing with slight interruption to the close of the Permian. The evidence of a Sub-Carboniferous

⁵ 1st Ann. Rept., Texas Geol. Survey, 1889, pp. 255–82.

⁶ This fact is proved by the existence of maible and flint pebbles in the Carboniferous, with the same structure that the materials at present have in the neighboring Silurian.

bed consists, so far as worked out, in an unconformity of marked extent between a series of limestone and an overlying series of sandstone and limestones, an unconformity in which more than 4,500 feet of upper Carboniferous beds are involved.⁷ These lower beds and the upper Carboniferous beds, filling, at the shore line, the bays of the older land, extended far to the westward and were represented in west Texas, in the Trans-Pecos region, by the deeper water strata which form the present Guadalupe Mountains. At first the deposits were those of an open sea but in the upper beds different conditions are indicated.

That part of the Carboniferous which lies immediately beneath the Permian, and which I have called the Coleman division of the Texas Carboniferous indicates mediterranean conditions, a foreshadowing of the oncoming of the Permian inland sea. The older land was skirted by a coastal strip formed by the recent Carboniferous strata now elevated above sea level. There was a gathering in of shore lines, and I conceive the conditions of this period to have been not unlike those of the present Gulf of Mexico. The southern and northern shores were older Palæozoic rocks skirted by a coastal strip of Carboniferous strata, and these two areas were now, if not before, connected areas. The other enclosing sides are at present unknown.⁸

The gathering in of shore lines thus early indicated, continued with no break, or at most with only a slight break, until a completely land locked sea was formed. In this the Red Beds of Permian age, consisting of a series of inland sea deposits, frequently gypsum bearing and saliferous, were deposited. These salt bearing beds moreover indicate an arid climate for this section, which would lead us to infer a considerable area of land. The land was made, however, without distortion of noticeable extent, except possibly in the older Silurian and pre-Silurian strata.

(c) *Jura-Trias Period of Denudation.*—The condition of Texas during the Jura-Trias period is but vaguely understood. In the main it was a land area, and the denudation of the period reduced it well down to base-level. This is proved by the contact of the

⁷ Tarr, 1st Ann. Rept., Geol. Survey Texas, 1889, pp. 201-203.

Tarr, Am. J. Sci., XL., p. 404.

Tarr, Am. J. Sci., XLIII., 1892, pp. 9-12.

Tarr, Am. Geol. Sept., 1890, pp. 145-153.

⁸ For a more complete discussion of this phase of the problem I refer to an article by the author on "The Permian of Texas," Am. J. Sci., XLIII, Jan. 1892, pp 9-12.

Cretaceous overlap, which is everywhere, on the Carboniferous, a gently undulating line, with no sharply defined buried topographic features. It was a plain and probably a base-leveled plain. The older Palæozoic core formed the highlands of the region, and here, in consequence of the harder nature of the rocks and their more variable character with reference to hardness and altitude, the topography was distinctly more diversified.

(*d*) *Cretaceous Subsidence*.—With the beginning of the Cretaceous period there came an extensive and rapid⁹ subsidence, during which both the upper and the lower Cretaceous beds were deposited. The history of this period has been so fully worked out by Prof. Hill and so clearly described by him in various places that I shall do no more than state the fact. This part of the history of Texas is already known to geologists. The several thousand feet of Cretaceous completely buried the older Palæozoic land as first pointed out by Prof. Hill.¹⁰ This fact has been disputed by Dr. Comstock¹¹ who has spent several years in a study of the older Palæozoic rocks of the Central Denuded Area. Prof. Hill reiterates his statement later and is supported in the conclusion by Mr. Walcott¹² and Dr. Curtice.¹³ I have studied the problem from a standpoint different from that of the geologists above referred to and am convinced of the accuracy of Prof. Hill's deductions, and, in the paper on this subject above referred to, have given my reasons for this conclusion, these being both geographic and geologic. Since they do not fall within the scope planned for this paper I make no further reference to them here.

This complete transformation of a large area of nearly base-leveled land to a condition of deep sea sedimentation lasted until mid Cretaceous time when there was an elevation followed by another depression in which the upper Cretaceous beds were formed. There was at this time, that is during the upper Cretaceous epoch, a period of volcanic eruption in the vicinity of and southwest of Austin, the relics of which remain now as low necks of nepheline basalt. These, the Shumard Knobs, are, according to Hill,¹⁴ marine volcanoes in the Cretaceous Sea.

⁹ For proofs of the rapid subsidence I refer to an article by the author in the *American Geologist*, Vol. IX, 1892, pp. 169-178.

¹⁰ *Am. J. Sci.*, XXXVII, 1889, p. 283.

¹¹ *First Ann. Rept.*, Texas Geol. Survey, 1889, pp. 315-318.

Second Ann. Rept., Texas Geol. Survey, 1890, pp. 663-664.

¹² *Bull. Geol. Soc. Am.*, 1890, Vol. II., pp. 522-3.

¹³ *Bull. Geol. Soc. Am.*, 1890, Vol., II., pp. 526-8.

¹⁴ *Am. Geol. Nov.* 1890, pp. 286-292.

(e) *Post Cretaceous Changes*.—With the close of the Cretaceous period of deposition there began the mountain building work which culminated in the formation of the Rocky Mountains and to which the present form of Texas is in large measure due. In the East it caused the bodily uplift of the great Cretaceous plain, the remnant of which forms the Grand Prairie. An extensive fault, the Balcones fault of Hill, occurred possibly at this time, and is at present an important feature in the topography of eastern Texas. It is, however, such a striking feature and so well marked that it more probably occurred during the Tertiary or possibly even during the Quaternary uplift, to be mentioned presently.

The Rocky Mountain uplift which formed the plateaus and plains of central Texas, by a bodily uplift more pronounced in the west, took, in the Trans-Pecos region, the form of mountain building. Little is known of these mountains, but the Guadalupe Mountains which the author has studied, are monoclinical in structure, faulted on the western side. Others are more complicated, and some are associated with igneous eruptions or intrusions. Little is known about this region other than that it is a mountain range and basin region in which Tertiary lakes lingered until the period of Quaternary desiccation caused them to disappear.

A period of sedimentation following the Cretaceous uplift admitted of the deposition of the Tertiary clays and sands, which, by their elevation, added another strip to the Texas region, that which Prof. Hill has designated the Eocene Lignite or Forest region. Again, in Quaternary time, another strip was added, and the Coastal Prairie is so recent that shells now living in the Gulf are enclosed in the strata as fossils. A slight submergence of very recent date is indicated by the fjorded character of the streams on the Texas coast.

The Llano Estacado plateau is said by Prof. Hill¹⁵ to be capped by lacustrine sediments of late Tertiary or Quaternary age and this forms another chapter in the history of Texas, but we have few details in regard to this most interesting episode.

(f) *Post Cretaceous Drainage*.—It has been my effort in the preceding pages to trace as briefly as possible the geological history of the development of the Texas region—the steps by which it has come to assume the present form. The minor details of the land sculpturing as revealed by the river histories registered in the topography remain to be considered. A few general points on the sub-

¹⁵ Am. Geol., V, 1890, pp. 27–29.

ject may well be stated here before taking up the detailed study. With a few exceptions this study is of necessity confined to east and central Texas for the reason that west Texas, or Trans-Pecos Texas, is practically an unknown land. That part which concerns us most at the present time, is the portion elevated during the beginning of the formation of the Rocky Mountains as a great plain, chiefly if not entirely Cretaceous covered, and dipping eastward. Upon this the streams have developed, being revived by the Tertiary and Quaternary uplift. They have in places cut through the Cretaceous covering and, in the Central Denuded Area, have revealed great areas of buried Palæozoic rocks upon which they are superimposed. The reason why the streams have cut through to the Palæozoic at this their most elevated portion is not now definitely certain. It may have been the result of mere chance, or it may be that this region, having a thinner cover than the other region, was first reached, and, being more resisting because relatively elevated and diversified, and consequently a region of excessive denudation, became a center of drainage. Another possibility is that the Palæozoic Highland was expressed in the Cretaceous sea by a dome-like bulging in the Cretaceous sediments, and consequently was the first land to be made and the first and most rapidly denuded. For a discussion of the subject I refer to my paper on the Cretaceous Covering of the Central Palæozoic of Texas.¹⁶

PART II.—PHYSIOGRAPHIC DESCRIPTION.

1.—GENERAL.

The different geographic units above mentioned exhibit different phenomena and it seems, therefore, best to divide the discussion so as to give each geographic unit a separate consideration. This division of the subject cannot be adhered to rigidly because the various regions merge one into the other and the physiography of one very often resembles closely that of another. Yet each geographic unit presents unique features and, for this reason, it seems necessary to consider them as units. Moreover it is the only method of treatment which seems possible without the introduction of much confusion.

2.—THE QUATERNARY COASTAL PRAIRIES.

(a) *Geographic Description.*—Of this plain Hill writes,¹⁷ "It is

¹⁶Am. Geol., Vol. IX, 1892, pp. 169–178.

¹⁷Am. Geol., V, p. 11.

perhaps the best example of a newly born topographic plain in this country." Of the same region Penrose says¹⁸ "the coast prairies reach inland along the Sabine about fifty miles, but as we go west they spread farther and farther toward the interior, until when we come to the Brazos, they reach up the river for over a hundred miles. Near the Gulf shore they are flat and low, rising twenty to thirty feet above the water, thickly covered with grass and cut by steep-sided channels of many rivers and creeks. The monotony of the scenery is broken only by the narrow strips of timber which follow the meandering course of the streams down toward the Gulf of Mexico." On its inner or western margin it becomes undulating and merges into the rolling timber area.

Where I crossed the plain from Houston to Galveston it is little more than an undrained swamp. The steep-sided stream channels are sunk but a few feet beneath the surface and between these are great flat-topped, undrained divides upon which water stands during the greater part of the year. Rushes and swamp grass have possession and even cattle find the plain too inhospitable for habitation. Now and then, though very rarely even along the railroad, on some slight elevation a settler has placed his house and a few cattle graze in the vicinity. Everywhere else there is one monotonous stretch of dead-level plain. So young is the plain that recent fossils at present living in the Gulf are preserved in the prairie strata.

(b) *Young, Consequent, and Extended Drainage*.—Two types of rivers exist upon this coastal plain: the extended rivers, having their supply in the interior, and the young consequent streams which are developing between these. The Brazos, Colorado and Trinity are instances of the former and innumerable creeks are examples of the latter.

The extended rivers, receiving their supply of water and sediment from the inland plains, reach the Quaternary prairies as full sized, well developed streams and they monopolize the drainage of the plain. As the plain was elevated they grew out across it and by their power, resulting from size and priority of location, they have seized upon the major part of the plain as their own. The extended course is consequent on the original slope of the plain; that is, Gulf-ward. In the spaces left undrained by these larger and stronger rivers consequent streams are now developing. The extended streams grow at their mouth, the smaller young streams

¹⁸First Am. Rept., Texas Geol. Survey, 1889, p. 7.

are growing at their headwaters. The time of occupancy by these two types of streams has been so short that the interspaces are flat-topped and undrained, and the channels steep-sided and cañon-like.

(c) *Estuarine Condition*.—Even in this brief period the streams of the coastal prairie have been subjected to an accident. All the larger streams are at their mouths estuarine. They are also flowing, even on the plain many miles from the shore, in channels with little slope. These facts record a slight submergence since the greatest elevation, though the phenomenon is also due in part to the overburdened condition of the streams.

(d) *Young, Growing Coast Line*.—The extended rivers helped to form the coastal plain when the shore line was farther inland, and they are now at work with the aid of tides, waves and currents in the construction of a similar plain along its margin. Each large river is overburdened with sediment derived from the Tertiary clays, the Cretaceous, and Palæozoic rocks, and this sediment is being used by the waves and tides in the construction of land. The coast line is growing outward. Shoals, bars, and islands are registers of this growth, and the beaches, even the much boasted beach at Galveston, upon which the surf rolls laden and muddy with river furnished sediment, show the progress of outward growth. The harbors of Texas exist because the river mouths are fjorded, and because protective bars and islands have been thrown across the mouths of the estuaries, by the currents laden with sediment brought down by the rivers. They are poor harbors because the excess of sediment thus furnished is being deposited in the estuaries. The engineering improvements proposed for the harbors of the Texas coast must take into account this outward growth of the coast line.

The bars thrown up along the Gulf coast line have enclosed lagoons, sometimes quite completely, and here is formed one of the few kinds of lacustrine basins in Texas.

3.—THE ROLLING FORESTED TERTIARY AREA.

(a) *Topographic Description*.—This country ¹⁹ consists largely of the inshore part of the bottom of the old Tertiary Sea, which once covered the whole Gulf coast. This area has been elevated into a

¹⁹The description in this paragraph is abstracted from Penrose's report on the Gulf Tertiary of east Texas. (First Ann. Rept., Texas Geol. Survey, 1889, pp. 7-13), the abstracts in most cases being verbatim quotations.

table-land one hundred to seven hundred feet above the sea level, sloping gradually to the southeast and emptying its waters in the same direction into the Gulf of Mexico. Since its elevation it has undergone great erosion and is still being denuded at a tremendous rate. The strata are all composed of sands and clays, and succumb very readily to the eroding action of atmospheric agencies. The result is that all that is left of the once level surface of this table-land are a few flat-topped hills and ridges. The highest points, locally called mountains, are buttes or mesas having their summits capped by an almost horizontal bed of iron ore or sandstone, and to this covering they owe their existence. A large part of this area is a heavily timbered region, and marks the southwestern terminus of the great Atlantic timber belt, extending from the Arctic regions continuously along the coast of the Atlantic Ocean and the Gulf of Mexico until it finally disappears in the mesquite and cactus prairies between the Colorado River and the Rio Grande.

(b) *Mature, Consequent and Extended Drainage.*—The conditions described above, under the Quaternary, in all probability are repetitions of similar conditions in the Tertiary area in earlier times. This area is composed of horizontal and cross-bedded strata, now partly consolidated clays and sands, which undoubtedly formed a coastal strip at the close of the late Tertiary uplift. Streams which had developed on the Cretaceous plains and had uncovered portions of the buried Palæozoic, extended across the coastal strip of Tertiary strata, and between them young consequent streams began their development. The Brazos, Trinity and Colorado were here, as in the present coastal strip, extended rivers. The then young consequent streams of the older plain, such as the Neches and Angelina, are now extended across the Quaternary plain.

The elevation of the old coastal strip was greater than that of the more recent one for it now rises on its inner margin, in some places, to an elevation of seven hundred feet above sea level and there is evidence that it extended farther inland at one time. The topographic development of this region of Tertiary strata has proceeded to the point of producing a rolling country of low and gently sloping hills with broad valleys. In other words it has proceeded as far as early maturity. It may seem at first thought that this is at variance with the description of the Cretaceous area which follows. Here the streams are topographically young, yet this land is vastly older. This apparent anomaly is due to three causes: first, the fact

that the streams on the Cretaceous have been rejuvenated by the late Tertiary and Quaternary elevation in the first of which the area under consideration was elevated above sea level as a young unscored plain; secondly, that the streams on the Tertiary are chiefly extended, hence well developed lower portions of streams and their development is more rapid than the headwater streams which are also higher above sea level and hence have a greater depth to cut through before reaching base level; and thirdly, the fact that the Tertiary strata are unconsolidated while those of the Cretaceous are in large part indurated. Topographic age is a relative term varying according to circumstances, not the least important of which is the character of the strata. In soft strata topographic maturity will be reached much sooner than in hard strata, other conditions being equal.

(c) *Origin of the Flood Plains.*—The broad flood plains of the forested area are worthy of some attention. In the spring and early summer such streams as the Brazos in this region overflow their banks and transform the swampy malarial plains upon either side into impassable lakes, very much as does the Red River of Arkansas. The immediate cause of this is the excessive floods which come from the rains at the headwaters. The reason why such excessive flooding is possible is that the rivers of Texas are overburdened streams. The sands and clays of the Permian and Carboniferous areas cause the streams which flow through them to be overburdened far up toward the headwaters, and this condition continues and increases through the Cretaceous and Tertiary areas. In the forested region, the slope being diminished as the sea is approached, much of the sediment burden can be carried no farther. This tendency to deposit the sediment in the stream beds has been exaggerated by the recent slight submergence indicated by the fjords and estuaries at the river mouths in the Quaternary plain. In this way the deposits near the mouths of the streams have been brought about in the effort to restore the profile of equilibrium, and secure a channel-way to the sea through which the sediment load can be transported. This establishment of the profile of equilibrium is now in progress and the flood plains are growing up stream.

For some reason there has been a change in conditions of recent date. Formerly the rivers flowing through this Tertiary area were able to keep their channels clear and carve them deeper. Now they are building them up, and this in spite of an elevation of some fifty

feet. This change is greater than can be accounted for by the recent slight submergence, and there is evidence that it began before the submergence, for the flood plains are broad and deep and consequently old, whereas the estuaries are so recent that they have hardly begun to be filled.

Whatever be the explanation it must be one whose chief factor is an increase in sediment, and for this two hypotheses suggest themselves. In the normal development of a stream there comes a time when, by the growth of headwaters, the supply of sediment exceeds the power of the stream to transport it and the stream becomes overburdened. Under different circumstances this condition appears at different times. In such rivers as the Platte it is a long enduring condition, in others it may never occur, but in general it is a stage in development. It is possible that the Texas streams have reached this stage.

From my knowledge of the Texas rivers I am inclined to believe that the explanation must be modified by the introduction of the second hypothesis. It is quite certain that the climate of west and central Texas has not long since changed from a moderately moist to an arid climate. This is indicated by the old lake basins, now nearly dry, in the Trans-Pecos region; and, in central Texas, by the headwaters of the Colorado, well defined valleys now abandoned through dessication, to be described later. Probably this change of climate was coincident with the change registered in Lake Bonneville, and consequently with the disappearance of the continental glaciers. During the moist period the soil was clothed with vegetation and the rains were more uniform and less violent than at present. Under the present conditions nearly every rain in the semi-arid region comes as a heavy fall, and, striking the barren plains, transports much sediment. An arid type of arroyo-like drainage has replaced the more perfectly developed drainage of the earlier period.

It seems to me quite certain that the extensive flood plains of the forested area are the result partly of a change in climate to more arid, partly of a stage in development when the overburdened condition of the rivers has been reached. What effect the Llano Estacado, which Professor Hill considers Quaternary Lake beds, may have in this connection I am unable to say. It would in all probability add one more factor to the problem and this another source of

sediment supply. The slight submergence of the coast line has merely increased the tendency to build flood plains.

(d) *Origin of Forests*.—The rolling Tertiary area is a forested area unlike the coastal prairies on the one side and the Cretaceous plain on the other. I am unable to say definitely why this is so. The soil is more sandy and consequently more porous than that of the Cretaceous and this in all probability is the reason why forests exist here.²⁰ The coastal strip is entirely too wet for forest growth.

(e) *Rio Grande Embayment*.—I have entirely omitted the consideration of the Rio Grande embayment for the reason that I have no personal knowledge respecting it, and indeed little is known about it. It is evident that the lower Rio Grande was estuarine in Tertiary times, but of the extent and nature of this I am unable to speak.

4—THE CRETACEOUS GRAND PRAIRIE.

(a) *Topographic Description*.—Professor R. T. Hill has so frequently described this region²¹ from various standpoints that I feel called upon to make in large measure merely a brief summary of his results. This great Cretaceous plateau is in reality made up of two plateaus separated by a quite continuous scarp, the Balcones scarp of Hill, in part. That portion of the plateau which lies to the east of this escarpment is called by him the Black Prairie region, while the name Grand Prairie is assigned to that part which lies to the west. The Black Prairie is a gently undulating plateau with varying width, merging to the east into the forested area, to the west ending abruptly at the base of the scarp. The soil is black and sticky when wet, whence its name, the Black Waxy Prairie.

The scarp is in part a scarp of erosion, but a fault scarp in the vicinity of Austin, and to the southwest as far as the Rio Grande. It forms a marked topographic feature, a rather abrupt wall rising to a height of two or three hundred feet. The fact that the fault is so plainly indicated in the topography seems to point to a recent origin, though this is advanced only tentatively. A number of large springs occur along the fault line.

²⁰Penrose states (First Ann. Rept., Texas Geol. Survey, 1889, p. 9) that the early settlers found this region much less densely timbered than at present. This was particularly the case on the uplands. He suggests as an explanation of this the habit which the Indians had of burning the tall grass in their search for game.

²¹See particularly, Am. Geol., Vol. V, 1890, pp. 9-29.

Nearly coincident with this line are a series of volcanic knobs, the Shumard knobs of Hill, and referred by him²² to marine volcanoes in the Cretaceous sea. It is not impossible that there exists here an old Cretaceous fault line, a line of weakness which in the Tertiary elevations furnished a slipping plain from which the present fault of the Balcones resulted. The Shumard knobs at present exist as a series of low, well-rounded hills rising out of the prairie, and made up of nepheline basalt.

The Grand Prairie proper consists of a series of nearly horizontal, gently east-dipping, alternating hard and soft beds of lower Cretaceous. Its eastern margin is regular, and coincides with the western margin of the Black Prairie. On the western edge, on the other hand, the escarpment is one of extreme irregularity and weird beauty. The Colorado River and its tributaries have here cut through the Cretaceous and reached the underlying Palæozoic rocks; and the young drainage, intensified by the sub-humid conditions of rainfall, has caused a marvellous complication of buttes, mesas, irregular parks, and projecting promontories. The young drainage has cut down to the base of the Cretaceous, but subærial denudation has not been able to keep pace with the down-cutting, and flat-topped divides remain between the streams. A hard stratum of limestone caps these buttes and mesas and is largely responsible for the type of topography. This irregular escarpment almost completely surrounds the region, so aptly called the Butte or Denuded region by Professor Hill, and far away from the scarp, out on the Carboniferous strata, isolated buttes, remnants of the former Cretaceous covering, still remain.

(b) *The Cross Timbers*.—This Grand Prairie region is treeless except for two narrow strips, the Cross Timbers, which extend approximately north and south across the prairie. Along the streams and in the rougher parts of the area live-oaks and other Texas trees grow in small groves or in isolated patches. The Cross Timbers early attracted the attention of the settlers and many speculations have been indulged in to account for their existence. Loughridge, for instance, in the Tenth Census report states that these occupy two old abandoned river beds. Hill has, however, shown²³ that this is not so, for the timber areas occupy two sandy strips which are not river beds but merely the outcrop of sandy layers in the Cretaceous.

²²Am. Geol., Nov. 1891, pp. 286-294.

²³Am. J. Sci., April, 1887.

Hill ascribes their presence here to the influence of the sand which, by its porous nature and the fact that it is a storehouse for moisture, renders tree growth possible, whereas the clays of the prairie are too close grained for forest growth. I find myself unable to agree with Prof. Hill on this point, for I believe the cause of the absence of forested areas on these plains is to be found in the habit which the Indians had of setting fire to the prairies in order to facilitate the search for game.²⁴ My reason for the belief is that wherever in this region, for any reason, the growth of grass is sparse, forests or groves or scattered trees grow. In the Carboniferous area, enclosed in part in this Grand Prairie, the hill sides are almost invariably covered with a sparse tree growth, whereas the low undulating divides are treeless, although there is very little if any difference in character of soil, except that the hill sides are more rocky. This is true on both limestone and sandstone soils. It seems to me much more reasonable to suppose that, being sandy, these areas supported a growth of vegetation too sparse to readily spread the prairie fires and were consequently protected from them and therefore are forested. From my view of the Cross Timbers in a drive across them I feel confident that a fire could not long burn in them, for they are low scrub oaks and very much scattered.

(c) *Rejuvenated Peneplain*.—The drainage of the Cretaceous plateau is young, or, more properly, rejuvenated. There are great areas of Cretaceous removed, so much indeed that I think it extremely unlikely that it has all been removed in the present cycle. The stripping of the covering from the central Palæozoic prairie, the removal of the upper Cretaceous beds from the Grand Prairie, and the uncovering of the Shumard Knobs and their subsequent denudation are hardly in keeping with the supposition that this work has been done by young streams. My acquaintance with the drainage of the Cretaceous Grand Prairie is so slight (being confined to the vicinity of Austin with the exception of one or two trips across it on the railroad) that I cannot state as a definite fact the history of the region which I suspect; but there is a line of reasoning which renders it highly probable that before the Tertiary elevation the Cretaceous was reduced nearly to sea level. It is as follows:—In the first place the vast denudation mentioned above suggests long continued erosion. At the beginning the Cretaceous was at least seven hundred feet lower than at present, and this condition

²⁴Shaler,—Aspects of the Earth,—New York, 1889, p. 287.

remained at least until the close of the Eocene, possibly to the beginning of the Quaternary. Such a lapse of time must have been represented by erosion amounting almost if not quite to base-leveling. It is moreover probable that the interior of Texas was very different from the present as regards geography. Portions of it were beneath the sea or in an inland sea condition. This applies particularly to the Trans-Pecos region and the Staked Plains. It was also, in all probability, much lower than at present, even more than seven hundred feet lower, for as yet the growth of the Rocky Mountains had hardly begun. It was probably this growth which raised the Tertiary above the sea, this elevation being represented by seven hundred feet or more at the margin of the Tertiary sea. Since the elevating force was to the west the elevation consisted in a tilting, the elevation increasing in the interior. This is shown by the dip of the beds of the Cretaceous and Tertiary.

If this line of argument is correct the interior of Texas was lower than at present by more than a thousand feet, hence the land to be base-leveled was less both in thickness and in areal extent. This renders base-levelling of Tertiary times more probable. An examination of the field with this possibility in mind ought to show evidence of this condition. The only field evidence corroborative of this hypothesis which I am able to give is a point which is very noticeable in the region which I have studied in some detail, namely, the Carboniferous. The rivers in this section, though young at present and consequently very rapid in flow, instead of pursuing direct courses, follow rock walled channels remarkable for their meandering. This is strikingly shown in the Brazos and the Colorado in the region under consideration. It seems difficult to explain these meandering courses upon any other supposition than an inheritance from a former plain.

I believe that further physiographic studies of the Texas region will show that at the close of the Cretaceous there was an elevation due to a recurrence of the mountain growth of the old buried mountainous areas of central Texas, which raised a portion of the Cretaceous above the sea. This portion, now known as the Central Denuded area was a moderately low land, which, during Tertiary times, suffered extensive denudation, becoming a peneplain. The Rocky Mountain elevation added to this area the plateau to the west and the Tertiary to the east, and by rejuvenation gave the streams new life and new tasks with which they are now wrestling.

Whatever the former condition of this area, the drainage is at present in a state of youth or early adolescence. Larger rivers, such as the Colorado, flow in deep cañons, sometimes with almost vertical walls and with small flood plains, sometimes with none. The river flow is rapid, and the channel is at times obstructed with rapids. Into these larger valleys side streams empty through narrow cañons with rapid slope, and the divides have not been reduced to a state of tolerable permanency but often remain gently rounded broad topped areas. This is particularly true of that part of the prairie immediately to the west of the Balcones scarp,—another suggestion of the recency of this fault. In the denuded Palæozoic area other conditions exist, as I shall attempt to show shortly; in the lower lying Tertiary area to the east, the beds being softer, the elevation less, and the streams overburdened, the topography, as has been already stated, is less abrupt, less distinctly young, and the streams, though rapid, are not carving their channels deeper but are building them higher in order to establish a profile of equilibrium, a slope down which the sediment load can all be carried.

5.—CENTRAL PALÆOZOIC DENUDED AREA.

(a) *Topographic Description.*—In this region there are three distinct classes of topographic relief, the result of erosion upon three different classes of rock, the Silurian, Carboniferous and Cretaceous. The Silurian, with its inherited rugged topography of pre-Cretaceous age, has, since the removal of the Cretaceous, been exposed to quite rapid denudation, because of its greater elevation. Consequently the Silurian area is a region of marked topographic diversity, and this feature tends to be preserved because of the great durability of the rock. Not only is this varied outline brought about by elevation, inherited relief and the hardness of the rock, but also because of the complicated stratigraphy which in a measure guides the erosion.

One can, in a measure, tell the difference between the Silurian and Carboniferous by the topographic outline, for the hills of the latter are more broadly flat-topped, though by no means as strikingly so as the Cretaceous. The butte and mesa type of erosion so characteristic of the Cretaceous in this region is so entirely absent from the Carboniferous that generally no difficulty is experienced in discriminating between Cretaceous and Carboniferous by the topographic features alone.

The Carboniferous has inherited from Pre-Cretaceous time a base-levelled surface, and where the Cretaceous has only recently been removed the Carboniferous hills are broad and flat-topped. All of the Carboniferous, excepting that close to the larger streams, might be said to have been recently uncovered; but generally the surface is more or less carved by recent erosion which has destroyed much of the inherited topographic individuality. In San Saba county, however, about midway between the Colorado and San Saba Rivers, there is a long flat-topped divide extending for a distance of twelve miles in an east and west direction, but in places somewhat destroyed by the headwater erosion of some small creeks. This divide is approximately the Pre-Carboniferous land surface, and that it has very recently been uncovered is proved by the fact that these hill-tops are all somewhat littered with pebbles of the Trinity (lowermost Cretaceous) conglomerate—the last remnant of the Cretaceous covering. The flat-topped divide is less than a mile in width. For the conquest of this the small tributaries of Richland Creek are combating with some small creek tributary directly to the Colorado. The latter have previously had the best in the contest and have pushed the divide back to within three miles of Richland Creek.

Away from the divide, and nearer to the center of strong erosion, that is near the large streams, the Carboniferous is very much cut up into sharp hills and deep valleys and this feature is now extending into the higher and more remote regions. Where denudation of this strong type has been for some time in progress in the Carboniferous area, two distinct types of topography have arisen, one in sections where the bed rock is of quite uniform character, the other in regions of greater lithologic diversity. The great sandstone area of San Saba county is a typical example of the former; and here sharply rising hills with deep valleys on the several sides have resulted. In portions less exposed to denudation the surface is gently undulating.

Where the lithologic character is diverse, long hills running northeast and southwest with steep bluffs on the southeast side result. This is the direct result of the effect of strike and dip, and furnishes an excellent example of monoclinal shifting of divides. In Coleman County the topography is distinctly of this type because here there are alternating beds of soft clays and hard limestones with a gentle dip to the northwest. The hills are step-like, and in travelling across the county one rises by a steep slope from one

plain to another, the face of the slope being clay, littered with bowlders dropped down from the overlying limestone stratum which forms the floor of the plain above. If these beds were horizontal there would be here a butte and mesa topography instead of a step-topography.

Almost completely surrounding this area is the irregular Cretaceous escarpment with its buttes and mesas, and, upon the Carboniferous itself, often many miles from this scarp, are degraded remnants of Cretaceous in isolated buttes, or small mesas, or in degraded patches the last remnants of former buttes. These buttes are capped by a hard limestone and once this is cut through and destroyed the complete destruction of the Cretaceous is easy, since the major part of the beds beneath are soft and quite incoherent. These buttes and mesas are here because they are divides between streams, and, as at the divide the development of the stream is least rapid, so here at the divides the removal of the Cretaceous covering has been least complete.

(b) *Peculiarities of Creek Erosion.*—The stream valleys of the central Texas region furnish interesting peculiarities, the result, in large measure, of the peculiar rainfall conditions. During the winter which I spent there, from November to February inclusive, there was not a single rain that raised the volume of the stream perceptibly; but in the spring and summer the country is liable to excessive rains and the streams to excessive floods. For the greater part of the year little erosive work is done but occasional floods do much more in a few days than is done during the entire year in a rainy country. The violence of this erosion is everywhere shown in the creeks both by the character of the bars and other deposits and, in the larger streams, by the presence of rafted logs well up in the tops of the pecan trees. On the Colorado I have seen large logs lodged in the trees fully fifty feet above the low water surface of the river.

Creek erosion under these circumstances differs in some minor respects in different parts of the region, particularly in the sandstone and limestone regions. In the Silurian, for instance, where the rocks are chiefly marble, the creek valleys are deep, precipitous and picturesque, with bluffs and isolated columns of limestone, and, over all, a beautiful mat of moss and ferns. Some of these valleys are fully seventy-five feet deep, yet, during the greater part of the year no water flows in these creeks, or, at the best, only a small, clear stream slowly trickles down. The water stands in pools and slowly

trickles for a short distance from pool to pool. The pools are generally rock walled but have not been formed in the manner of pot holes. The original beginning of a pool may have been after the manner of mechanically formed pot holes or may have been from some chemical weakness of the rock. Some of these pools which are many yards in extent and very irregular, are plainly the result of corrosion chiefly, a process which is continually extending the area of the pool since the water is constantly standing in it. Small waterfalls of similar origin are quite prevalent; but nothing shows the effect of corrosion as well as the undercut terraces common in the limestone of the Silurian, Carboniferous and Cretaceous. These terraces, which are in the form of long caves parallel to the course of the stream, mark the ordinary high water stage of the stream. They bear a general resemblance to some sea caves and in some cases are of mechanical origin where the high water stage coincides with some lithologic weakness, as is often the case in the Cretaceous, but, more frequently, and particularly in the Silurian and Carboniferous, they are the direct result of corrosive action of flood water. Sometimes one or two of these benches, somewhat destroyed, by sub-aerial denudation, exist on the bluffs above the one at present forming, marking former high stages when the river bed was higher. In these creek bluffs, from ten to fifty feet above the creek bed, may also be seen actual caves extending far into the wall, marking the former existence of underground streams or springs at a time when the bed of the creek was much higher than at present. Springs, perhaps similar to what these formerly were, are quite common in the Silurian, as for instance, in Wallace Creek where several large springs bubble up from the creek bed at the base of a high bluff of Silurian magnesian marble.

The streams of the sandstone region, of which Antelope Creek in Mills County may be taken as a typical example, present the same general features as those in the limestone; but the walls are rarely as steep and high and caves are seldom seen. This is the natural result of the difference in lithologic character, and for the same reason the pools are not of corrosive but of mechanical origin. In the great supply of sediment produced, frequently from the denudation of the Trinity conglomerate and sands of the lower Cretaceous, the floods find more material than can be carried away and the stream bed is littered with bars and small deltas, which, during the greater part of the year, form the enclosing sides of temporary pools, some-

times several hundred feet in length. Where the creek flows through a flood plain of gravel the channel is between gravel banks, generally less than thirty-five feet wide and twenty-five feet deep. At flood time not only is the channel filled, but the surrounding plain is covered with water for some distance, and during these times the erosive work of the year is done.

(c) *Effect of the Superimposition of the Colorado on the Silurian.*

(i) *Temporary Base Level.*—The Colorado River and its tributaries which drain this region, are superimposed through the Cretaceous upon the buried Palæozoic. It so happens that the Colorado itself has found, in its down cutting, a hard spur of Silurian marble and it is now wrestling with this obstacle. Over this spur the current flows with numerous rapids, and the stream is here very busy deepening its channel; the precipitous walls of its cañon, which begin here, show that the work has for some time been in progress. The softer Carboniferous rocks upstream from this, yield much more readily and the stream above the Silurian is waiting for the progress of the work below. The river is eroding on the Silurian but is building up on the Carboniferous for a score of miles above the natural dam, since the river is always heavily burdened.

This accident to the river has given rise to several interesting peculiarities, not only the river itself but all its large tributaries being influenced by the retardation. They have reached a temporary base level, their mouths are widening and extensive flood plains are being built. This is seen in the Pecan Bayou and in the San Saba River. The latter in its upper course flows in a deep cañon in the Silurian where it is still at work eroding, but for eight or ten miles from its mouth it has reached the temporary base-level and is not at work eroding its channel.

The flood plain of the Colorado is frequently fifty feet deep and is being rapidly built up. This is proved by buried trees, both dead stumps and partly buried living pecans. In flood-time great quantities of sediment are brought down from the headwaters and deposited here and during the winter very little is done toward removing this material, for even then the river is heavily burdened.

In a river of such habits as the Colorado the valley is, as would be expected, peculiar. The ordinary channel, though quite wide and deep, is incapable of holding even the ordinary floods. Such floods, which may occur several times in a year and last for several days, do not rise to the level of the flood plain proper, but

have carved out a channel in this flood plain nearly twice as wide as the natural channel. The greater spring floods extend even above this channel and cover the neighboring flood plain. Thus the valley of the Colorado is terraced, the first terrace being about thirty-five feet above the bed of the low-water channel, and the second, or flood plain proper, fifteen feet or thereabouts above the first. The first or high water terrace is sometimes on both sides of the river, though generally on one side better developed than on the other. The second or flood plain terrace is usually well developed on both sides. This form of terrace is not without its significance in connection with some of the river terraces of the glacial belt.²⁵

The Colorado which, as suggested above, is a young stream probably because of the rejuvenating influence of the Tertiary uplift, shows all the signs of youth. In the hard Silurian not only is the valley a cañon, but the channel is marked by numerous rapids. On the softer Carboniferous the cañon is disappearing, particularly where the retarding influence of the hard Silurian barriers is felt. The tributaries, and the river itself above the temporarily base-levelled parts, are rapidly at work, and deep and narrow cañon valleys with rapid slope are the result.

(ii) *Loss of Drainage Territory.*—The influence of the Silurian barrier has made itself felt in another respect. As has been stated, the eastern border of the denuded area is an escarpment of Cretaceous of irregular form—a region of buttes and mesas. This escarpment is a part of the valley of the Colorado and the minor details of sculpturing are the result of the erosive work of the tributaries to the Colorado. Only a few miles from the main river (six to ten miles) there is a flat-topped divide separating the waters of the Brazos from those of the Colorado. The former has tributaries here that have to flow seventy-five miles before emptying into the main river. In other words, the Brazos has pushed its conquest, by headwater erosion, into the territory of the Colorado and has placed the divide only a few miles from the latter.

The reason for this seems quite certainly to be the influence of the Silurian barrier. This explanation will be found in more detail elsewhere.²⁶ It is, briefly, that the two rivers, the Brazos and the Colorado, are superimposed through the Cretaceous on the Palæozoic, but the latter, encountering the hard Silurian, has had its down cutting retarded, whereas the Brazos has had only the much softer

²⁵Tarr, *Am. J. Sci.*, XLIV, 1892, pp. 59-61.

Carboniferous beds to cut through, and these higher up in its course. This has consequently given to the Brazos tributaries much more power than is possessed by those of the Colorado. The Colorado flows in a channel between eleven and twelve hundred feet above sea-level, just above the Silurian, whereas the Brazos east of here is only half that elevation.

(d) *Adjusted Stream Courses.*—The valley of the Colorado in this vicinity is remarkable for its serpentine course. In one place the river flows in a bend six miles long where a cut-off would reduce the distance to two miles. Along the boundary of San Saba county the river flows fifty miles, and, at the end of this distance, is only thirty miles from the first point. The valley here is a cañon, somewhat degraded it is true, but nevertheless the serpentine course is one in rock walls, not upon a flood plain. I have suggested in an earlier part of this paper that this course may be in a large measure an inherited course from a Tertiary peneplain, formed before the elevation recorded both by the Tertiary forested area and by the rejuvenated condition of the streams in the Cretaceous. The fact that the Brazos has much the same peculiarity supports this hypothesis.

While I believe this to be a true cause I am equally convinced that it is not the sole cause. The entire drainage system of the Colorado in the denuded area is superimposed.²⁷ It is in consequence not in accord with the revealed structure, for its course was originally consequent on a Cretaceous surface, and this course is now enforced upon it in spite of the altered condition. It is, however, a habit of rivers to attempt adjustment under such conditions and to be influenced by the revealed structure; and, as time goes on, this adjustment becomes more complete. As I have shown in the article cited many of the tributaries to the Colorado are quite in accord with the Carboniferous structure, particularly in the regions that have been longest exposed, and in the smaller streams. This has given rise to strike valleys which, in the vicinity of the Cretaceous, change to unadjusted courses.

Dr. Comstock²⁸ has called attention to the quite perfect accord of the streams on the Silurian to the more complicated structure, this being the result, in a large measure, of the longer exposure of this region, by the early removal of the Cretaceous.

²⁶Tarr, Am. J. Sci., XL, 1890, pp. 359-362.

²⁷For a discussion of this subject see an article by the author in Am. J. Sci., XL, 1890, pp. 359-362.

²⁸Second Ann. Report, Geol. Survey Texas, 1890, p. 664.

The Colorado itself shows signs of attempts at adjustment. The general course of the Colorado is across the strike of the Carboniferous, but in several of the loops the two long sides are in the direction of the strike while the short side is at right angles to this. The river is there locally in adjustment. While this *may* be accidental, it seems hardly possible when we take into consideration the number of instances where it may be noticed.

(e) *Summary of the History of the Colorado.*—To briefly summarize the history of the Colorado in this region, as I interpret it, it may be said that the river appears to have begun upon the Cretaceous which in this region was first to be raised above the sea, at the close of the Cretaceous. The long stand indicated by the Tertiary deposits gave the rivers time to reduce the elevated portion approximately to base-level, and the present serpentine courses of the streams are an inheritance from this period.

The late Tertiary elevation of seven hundred feet, and probably more, rejuvenated the streams, and this accounts for the signs of youthfulness now apparent. The later Quaternary elevation has produced no marked effect here. The Colorado, being superimposed upon the Silurian, is retarded in its development and has been robbed by the Brazos of much of the drainage territory which would normally belong to it. It has also, above the barrier, been reduced to a temporary base-level and its cañon is being degraded and its channel even being built up. Both the smaller tributaries and the Colorado itself are adjusting themselves to the structure of the Carboniferous upon which they have been superimposed.

6.—THE ARID PLATEAU.

(a) *Topographic Description.*—My knowledge of the plains is confined to a single journey across them by wagon and this description must therefore be very general; but the plains are very monotonous and one becomes acquainted with their general physical features even in such a hasty reconnaissance. It is a great semi-arid plain, truly arid in the west, with isolated buttes here and there. These buttes are in part of Cretaceous strata, but there are many formed of Permian beds. They are the remnants of layers which were once continuous. The greater part of the area is Permian and the soil is red while the water is alkaline or saline for the reason that these beds are inland sea deposits.

The Staked Plains cross the line of the Texas and Pacific railway in the neighborhood of Marienfeld presenting here a low wall or

escarpment; and about fifty miles west of here is another escarpment, facing west, which makes the western edge of the Llano Estacado. These plains are narrow here, this being the southern angle of the triangle formed by these bounding escarpments. The plains themselves are gently undulating and unscored by erosion. Farther north they are traversed by deep cañons, but here almost no drainage lines are apparent.

(b) *River Valleys Abandoned through Dessication.*—A careful study of these plains along the eastern part of the Llano Estacado will reveal some interesting facts, and I believe it is to the drainage lines that we will have to look for a solution of the history of this region. I can do no more than throw out a hint. The streams have carried more water than at present. This may show nothing more than a decrease in rainfall, or it may be the key to a complicated history.

From the Red Fork of the Colorado River, near Colorado City, to the Pecos, a distance of not less than one hundred and seventy-five miles, there was not, in April, 1890, a single flowing stream, yet the maps show several large branches of the Colorado crossing the line travelled. Three of these in particular, Girard Creek and two branches of the Concho River, are on the map made to rise far up in the Staked Plains. The Concho I crossed without being aware of the fact, for the valley of each branch is a broad valley with gently sloping sides and no channel. This is not a case of "arroyo" type of drainage, that is, a channel which occasionally carries floods. It is an old abandoned valley.

Girard Creek, which I was able to study more carefully, is of the same type, but less distinctly dessicated, being intermediate in degree of abandonment between the Colorado proper and the Concho. From Big Springs westward for six miles the valley averages a mile in width and is bounded by degraded bluffs from fifty to one hundred feet in height. There is no channel, but the valley bottom is a series of alkaline flats of the playa type, between cone deltas formed by the wash from the valley sides. These alluvial cones frequently extend completely across the valley and are overgrown by mesquite, showing quite plainly that no flow of water occurs in the valley. The flats between these cones resemble in appearance the estuarine marshes of the northeastern coast. Below Big Springs the channel is clear, and the drainage is young, being of the strong

arroyo type of the arid regions. I am puzzled to know the reasons for these peculiarities.

(c) *Æolian Deposits in the Pecos Valley*.—At the western base of the Staked Plains, along the escarpment of the Pecos Valley there is an extensive æolian deposit about fifteen miles in width. Professor Hill²⁹ states that this strip of sand is fully one hundred miles in length, extending up into Eddy County, New Mexico. It is plainly due to the prevailing west winds (as suggested by Hill) which have heaped the sands here at the base of the escarpment. It is the most absolute desert waste I ever chanced to see. Crater-like pits and cones of the sand dune type are here most perfectly developed, and the sparse sand-plant growth serves only partially to keep the sand in place.

It was my ill-fortune to be obliged to study this deposit quite carefully, for my team was unable to carry the loaded wagon over the sandy trail into which the wheels sunk, often to the hub. The difficulties of the trip were increased manifold by the sharp grades caused by the pits and cones, and by the shifting sands. Abandoned wagons proved that I was not the first to find the difficulties of the sandy strip. Being informed of the existence of a ranch a dozen or fifteen miles to the north I started on horseback in search of aid. Mile after mile I travelled in the hot sun with the drifting sand blowing in my face. Everywhere the same scene was before my eyes, the escarpment to the east being my only topographic guide. At last I turned back unsuccessful in my search. My tent was banked up with sand, sand was on everything and in everything. At night the eddies of wind would start whirls of sand within the tent, and cooking was quite out of the question. With four horses I was barely able to get my wagon, not a very heavy one, across this strip of sand.

So far as I know this deposit is unique in this country in point of size. Blown as it is quite constantly at the face of the escarpment it must be a powerful agent of erosion, and it is not impossible that this escarpment owes its present position in large measure to æolian action. The Pecos River is twenty-five or thirty miles away and though this was undoubtedly the originator of the escarpment, its present position is due to recession, and, I believe, recession brought about in part by the continual blowing of sand at its base.

²⁹Hill, *Am. Geol.*, Vol. VII, 1891, p. 369.

7.—THE TRANS-PECOS REGION.

(a) *Topographic Description*.—This is almost a terra incognita. It is in brief a region of mountains and basins, the highest mountains being the Guadalupe Mountains which extend from New Mexico into Texas. This is a faulted monocline, rising to the south, where, at Guadalupe Peak, it has an elevation of fully 8,000 feet above sea level and 3,000 feet above the plateau, being terminated by a sheer precipice 2,000 feet in height. It is a mountain of Carboniferous limestone faulted in the western side. Other mountains are associated with igneous action, but our knowledge of them is extremely limited.

(b) *Erosion in the Guadalupe Mountains*.³⁰—I introduce here a few notes on the topography of the Guadalupe Mountains taken during a brief sojourn there. The dip of the strata is to the east, gently at the base of the mountains, increasing to an angle of fifteen degrees or thereabout, then becoming nearly horizontal to the west bounding fault beyond which the dip is steeply west. The west dipping rocks, the downthrow of the fault, form the western foot hills. The drainage is chiefly to the east, being consequent on the structure, and therefore long cañons enter from the east well up to the western edge of the mountains, and the west flowing streams are small and short.

Of the east flowing streams McKitterick cañon is a typical example. For two miles from its exit from the mountain, this mountain gorge is accessible to wagons, but beyond this travel on foot is possible only with difficulty. It is extraordinarily rough, being bounded by precipices and steeply sloping sides rising to a height of fully two thousand feet; and the valley is littered with huge boulders and fragments of the cliff which have dropped down from the valley side. The slope of the valley walls is rarely less than thirty degrees and there are sheer precipices of magnesian limestone rising to a height of from one thousand to eighteen hundred feet. There are several hundred of these precipices and it is only rarely that the mountain top is accessible from the interior gorges. There is no soil on these slopes which are either bare bed rock or boulder strewn. The vegetation is of the arid type, except in the shaded valleys or well up on the mountain top, where fair sized pines and cedars grow. Snow accumulates in the cañons but disappears in

³⁰ See Bull. 3 Texas Geol. Survey, 1892, Reconnaissance of the Guadalupe Mountains, by R. S. Tarr.

early spring, and high up in the mountain rains are frequent during the spring and summer. In nearly all the cañons there are ever-flowing springs which furnish a stream of cold water ; but this disappears near the exit of the mountain stream and beyond the mountain the valley is a broad boulder-strewn channel carrying water only spasmodically. A rain in the mountains suddenly fills the channel with a seething torrent, which advances with a solid front like a wave, and the force of these floods is shown by the large pebbles and small boulders of the mountain limestone in the stream channel, many miles from the mountain.

That the valley is being rapidly deepened in the mountain is proved by the occurrence of a cemented conglomerate, a river bed conglomerate, clinging to the sides of the cañon at an elevation of fifty feet above the present channel. A similar conglomerate is now forming in the channel. Most of the annual erosion is done in a very short period of time, since during most of the year only a small, clear stream of spring water flows for a short distance. During the remainder of the year the down cutting is chiefly done by corrosion and this mainly in the upper course. The stream is strongly impregnated with lime, and as it descends and is subjected to evaporation the lime solution becomes supercharged and a tufaceous deposit is formed. Thus in the lower two or three miles the stream flows in a cemented pebbly bed while above this it flows chiefly on bed rock in a corroded valley. The tufaceous deposit encloses vegetable remains as well as pebbles.

Corrosive work is well shown in the hillsides, for the compact limestone is ridged and furrowed into an almost perfect imitation, in miniature, of mountain structure of accentuated topography. So roughened is the surface from this cause that the rock has the feeling to the feet and hands of a slaggy lava flow, and so perfect is this resemblance that the ranchmen compare it with glass and call it porphyry and granite, which led me to expect to find eruptive rocks in the mountains.

(c) *Quaternary Conglomerate*.—Along the eastern base of the mountains, extending well out on the plateau, is a conglomerate composed of mountain pebbles and often cemented with a tufaceous cement. This deposit is frequently many feet in thickness and rests unconformably on the Carboniferous. As the source is approached, that is near the mountain base, the fragments become larger and more angular. It has been inferred by some that this

represents a marine formation of Quaternary age, but without being able to disprove this I would suggest another cause which seems equally possible. It seems to me that this is no more than a gravel slope formed in part from the wash from the mountains, but having chiefly been brought down by the mountain streams and deposited in their channels, which have since been abandoned. Just such deposits are at present found in the broad stream valleys and if they should abandon their course the present stream bed deposits would remain to cap the hill tops when the general level of the region was lowered.

(d) *Dessicated Quaternary Lakes*.—There are in this region many lake basins of Quaternary age. One of these, Crow Flat Valley, I have studied in part. The fault scarp of the Guadalupe Mountains and the foot of the hills at its base form the eastern boundary of this lake. The other enclosing walls I have not seen. It is in part a synclinal valley formed by the dragging up of its strata on the east by the Guadalupe fault. The Crow Flat is a level plain, deeply filled with silt, at least forty feet deep, of a very fine quality, and having shore lines and deltas on either side. Its extent I am unable to state even approximately.

The lake is not quite extinct. It is a catchment basin for a large area and water is found throughout the valley at a depth of from five to forty feet in the lake silts. It is invariably alkaline, frequently saline. In the lowest portion of the valley the water comes to the surface in a great salt, marshy area, upon which a crust of salt exists. Alkaline flats and marshy areas are common, and gypsum deposits occur in several places. There is a gypsum stratum quite uniform in extent and in one place a dune-like accumulation of gypsum sand. This is but one of a series of dessicated lake basins in this region, none of which have been studied except in a hurried reconnoissance.

(e) *The Rio Grande and Rio Pecos*.—I am unable to say anything about the Rio Grande and Pecos Rivers in Texas. Both of these rise in the northern regions, in the mountains, and enter Texas as well defined and overburdened streams. Their Texas tributaries are nearly all of the arid arroyo type, carrying water only in times of heavy rains. Of these two large rivers I have seen only enough to convince me that they have an interesting history, but my knowledge of them is too indefinite to admit of the statement of my suspicions concerning this history.

8.—ABSENCE OF LARGE LAKES IN TEXAS.

It is a striking fact, that in a State covering an area as great as that of Texas, there is not a single large lake. Almost every other geographic form is represented, often in great variety, and the climatic conditions vary from moist to arid.

The lagoons of the sea shore near river mouths and in other favorable situations are perhaps the nearest approach to lakes in the state. The young land, as yet hardly land, encloses temporary lakes of saline water, which on the one hand are liable to destruction by the sea, or on the other to be quickly filled by the sediment of the streams.

The Tertiary and Cretaceous plains have been raised above the sea without sufficient structural features for lake formation. They consist of gently dipping strata and the lakes, which may have originally existed in early shallow inequalities, have been long since removed by the establishment of drainage. In the flood plains of the Tertiary district there are lakes of small size, according to Penrose who writes³¹ "lakes are of a very rare occurrence, and are never seen except in river bottoms, where they form muddy lagoons abounding in fish and generally fed by springs. They are often of considerable depth, and are connected with the main river by narrow channels." It seems probable that these lagoons are unfilled portions of abandoned river channels. Penrose states that in the Tertiary district he saw but one lake in the uplands, this amounting to little more than a large spring, having a diameter of about two hundred yards.

In central Texas the river erosion has uncovered the Carboniferous from beneath the Cretaceous, and the drainage, although superimposed, is establishing itself without the presence of lakes. In this section, in places where side streams have been held back by the effort of the main stream to overcome some barrier below, extensive flood plains have been built up in the lower part of the valley of the small stream and here lagoons and oxbow lakes are sometimes found. This is the case in the lower Pecan Bayou and San Saba River, both tributaries to the Colorado. These streams are laked in their lower course by the upbuilding of the flood plain of the Colorado due to the retardation in its down-cutting caused by the Silurian barrier. During the dry season all the medium sized streams of the semi-arid belt become a chain of lakes of extremely

³¹First Ann. Report, Texas Geol. Survey, 1889, p. 11.

small size, for the water stands in pools of varying size and trickles from one to another in a tiny stream. These pools are enclosed sometimes by bars and deltas, sometimes by walls of solid rock, the pools themselves being the result of corrosion.

The elevated plateau region west of this and east of the Pecos River contains a number of lake basins of sink-hole type, but no water, or at best very little, stands in them. Very probably there are sink-hole basins on the Cretaceous limestone in east central Texas. Still farther west, in the Trans-Pecos region, there are several large lake basins, abandoned either in part or entirely, by dessication. Here lakes of consequent origin, the result of mountain deformation, have existed and will exist again if the conditions of rainfall become favorable.

Hence it is that Texas contains no large lakes: first, because there are no regions of striking structural features, except one (the older Palæozoic area) in which erosion has long been in progress, and its lakes long since destroyed, and one in a region too dry for the existence of lakes; and secondly, because erosion has tapped the shallow lakes that formerly, no doubt, existed on the new Cretaceous and Tertiary land. Sink holes in limestone regions frequently containing small and shallow bodies of water, lagoons on the sea shore, and oxbow lakes in the flood plains, constitute the major part of the Texas lakes. To these might be added the expanded springs, the laked streams caused by the overburdened condition of the main stream (Pecan Bayou and San Saba River tributary to the Colorado), and the chain of pools of the sub-humid region, formed by the dessication of the river. The salt lakes, playas and alkaline marshes and flats of the Trans-Pecos region are the dessicated remnants of lakes, formerly of greater size, just as the pools are the result of the annual dessication of normally continuous streams.

9.—SUMMARY.

The State of Texas is a series of prairies, plains and plateaus, low coastal plains in the east, elevated plateaus in the center, and in the extreme west a plateau broken by mountain ranges. A buried land, now uncovered, forms a central hilly district. In climate the State varies from the moist Gulf coast to the truly arid Trans-Pecos region.

The evolution of the Texas region began, so far as our present records can show, with an old Palæozoic or Pre-Palæozoic mountainous land which was denuded at the beginning of Carboniferous

times to an old topographic form, not unlike the hilly region of southern New England. The Carboniferous beds were added to this land, by elevation, first as a coastal strip, even before the end of the Carboniferous. A gathering in of shore lines formed a great interior sea, later a completely land-locked dead sea in which Permian beds were deposited; and from the close of the Permian to the beginning of the Cretaceous there was a period of denudation during which the younger Palæozoic beds were reduced to base-level and the older mountainous areas still farther degraded. A rapid subsidence lowered the entire region beneath the Cretaceous sea, then at the close of the Cretaceous the land was elevated, possibly by a renewal of the mountain-building forces of the central area. The Rocky Mountain uplift caused an uptilting, raising the land still higher, and adding the Tertiary coastal strip to the Cretaceous. A later uplift added the coastal prairies and a recent slight subsidence has completed this record of change, and has given us the Texas region.

Drainage, established upon the part first raised, has stripped off the Cretaceous covering from a portion of the buried Palæozoic. The consequent streams reduced this to an approximate base-level, and by the more recent elevations these streams have been rejuvenated in the older region and have become extended streams in the newer regions, and, in the latter, young consequent streams have also been formed. The entire drainage is consequent, but the streams of the central Palæozoic are superimposed, and this has given rise to several interesting peculiarities, among others the reaching of a temporary base-level by the Colorado and its tributaries above the Silurian barrier, the consequent degradation of its cañon, and the formation of extensive flood plains. The Colorado through this cause has also lost some of its drainage area, and the tributaries, and the Colorado itself, are adjusting themselves to the revealed structure upon which they are superimposed.

The climate of western Texas has also become more arid and the effect of this is shown by the dessication of lake basins in the Trans-Pecos region, the abandonment of streams in central west Texas and in the growth of flood plains in the Tertiary forested area.

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